# Before the
# Federal Communications Commission
# Washington, DC 20554

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| In the Matter of<br><br>Revision of Part 15 of the FCC's Rules Regarding Ultra-wideband Transmission Systems | ET Docket 98-153 |

## Comments of Time Domain Corporation


7057 Old Madison Pike
Huntsville, AL 35806


September 12, 2000

# Executive Summary

Ultra-Wideband ("UWB") technologies will save lives, create new services and opportunities for consumers, and enhance the efficient use of spectrum. Time Domain Corporation ("TDC") commends the Commission for issuing this Notice of Proposed Rule Making ("NPRM") on Ultra-Wideband technologies. This NPRM provides the opportunity for all parties to participate and submit information so that the Commission may fully consider the issues associated with authorization of UWB devices. The issues surrounding UWB have been under discussion for over ten years in a variety of forums and proceedings, and as the NPRM recognizes, it is now time to act.

UWB technology can increase the security of law enforcement, public safety and military personnel while enhancing their ability to protect, rescue and defend. UWB applications can enhance safety in and around airports and in automobiles. The technology can also help to detect highway and bridge faults, locate buried landmines, track hazardous substances, and find victims in collapsed buildings or avalanches. UWB applications can benefit the U.S. military by protecting the lives of soldiers and extending the capabilities of current technologies. The cutting-edge nature of this technology and its potential to free up scarce spectrum resources to other uses suggests that the successful deployment of UWB technology will have a marked and positive impact on domestic economic growth as well as global technological and competitive leadership.

While having the potential to create entirely new products and services to benefit consumers, UWB technology faces hurdles to achieve widespread deployment. A major obstacle that prevents industry from further exploring the many applications and providing them to consumers is the need for Commission rules accommodating their use. The challenge for the Commission is to act timely and responsibly, address legitimate concerns, and adopt appropriate UWB regulations to enable the technology to reach its full potential.

UWB provides an important new variation on the successful spectrum-sharing regime established by the Commission in Part 15 that effectively increases the utilization of existing spectrum. Current FCC regulations allow billions of electronic devices, including 1 GHz PCs, to emit signals with similar frequency characteristics and with the same or greater signal strength as proposed for UWB signals. TDC urges the Commission to adopt regulations in this proceeding that will allow UWB devices to operate with signal levels up to the Part 15 general limits it has already authorized for billions of digital devices.

TDC is concerned that the Commission is considering regulations that call for a significant reduction in signal strength below 2 GHz. Because the signals it is proposing are at or below the well established Part 15 limits, TDC firmly believes that UWB will not cause harmful interference. In addition to the multitude of unintentional emitters already operating in the potentially affected bands, commercial and government interests have been using UWB ground-penetrating radar systems for decades apparently with no known reports of causing harmful interference.

Other key points that TDC makes in response to the issues raised in the NPRM are as follows:

- The proposed 12 dB decrease in field strength below 2 GHz would drastically alter the key characteristics inherent in UWB signals by affecting the signal's pulse shape. Such a requirement would force UWB communications and radar system designers to use a higher frequency signal with different and potentially unsatisfactory propagation characteristics.

- TDC supports the Commission's proposal to use the DARPA definition for UWB signals, but suggests that the Commission define UWB solely in terms of relative bandwidth. Relative bandwidth is the one feature of the UWB signal that provides the most notable benefits of the technology.

- TDC agrees with the FCC's proposal to use the –10 dB bandwidth for signal measurements, because, as TDC shows herein, it is extremely difficult to reliably measure the –20 dB bandwidth.

- TDC observes that many Part 15 intentional and unintentional emitters have very similar emissions characteristics. The interference potential from UWB intentional emitters is consistent with that of digital devices regulated in Part 15 as unintentional emitters.

- TDC agrees with the FCC Technology Advisory Council, Spectrum Management Focus Group, that the noise floor of a receiver will be set by the closest UWB transmitter only, and observes the critical need to account for real-world UWB operational scenarios, which include the operational duty cycle, on/off time duty cycle, propagation losses, victim receiver antenna gain and pattern, ambient noise, and UWB antenna polarization.

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In sum, TDC urges the FCC to open the way to implementation of technologies that can profoundly change the nature and scope of wireless applications. Well-reasoned changes to current regulations will provide significant and far-reaching public benefits in the course of UWB evolution and development.

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### Introduction

These comments respond to the Notice of Proposed Rule Making ("NPRM"), *Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems,* ET Docket 98-153, released on May 11, 2000. Time Domain Corporation ("TDC") strongly supports the Commission's actions in this NPRM. The Commission has designed a sound plan to develop new rules that permit the operation of equipment using Ultra-Wideband ("UWB") technology, while ensuring that existing licensees, including safety-of-life services, are protected from harmful interference.[1] The NPRM demonstrates that the Commission recognizes the benefits that UWB systems offer and seeks to fulfill its responsibilities to serve the public by fostering the development of beneficial new technologies while protecting the integrity of the electromagnetic spectrum.

There is widespread recognition that UWB is an important technological breakthrough in the increasingly dynamic worlds of radar and wireless communications.

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[1] *See* 47 C.F.R. § 15.5 (1999).

It has been suggested that the potential impact of UWB on the wireless industry, the economy and the general public may be profound.[2] For the purposes of this rulemaking, TDC will address what is known today about the technology and its possible applications.

The central question for this rulemaking is whether UWB technology will be afforded the opportunity to explore fully its potential in the marketplace or whether it will fall victim – either through unnecessary delay or overly restrictive regulation – to ungrounded fears. TDC strongly believes that rapid deployment of UWB devices is in the public interest and can be achieved by regulations that allow for compatible spectrum sharing with existing services. Indeed, because UWB provides capabilities previously unavailable and because many of its applications can operate successfully at the existing Part 15 limits for unintentional radiators, this technology will complement these services, and lessen the pressure on current spectrum usage.

The Commission has structured this rulemaking correctly. It is comprehensive, fully cognizant of the Commission's obligations to foster new and innovative technologies, and respectful of the needs and interests of incumbent users. The latter part of these comments will address the rulemaking's detailed technical proposals and requests for comment. The part that follows below summarizes the public interest implications of UWB, which cannot be realized without support from the Commission.

## The Public Benefits Of UWB Are Numerous And Compelling

### *The NPRM Recognizes that UWB Technology Can Benefit the Public*

The NPRM provides an excellent summary of the potential for UWB technology to deliver unique solutions to pressing requirements. The Commission recognizes that the

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[2] *USA Today* has described UWB technology in a double cover story as "an invention that could change the world?" (USA Today, Apr. 9, 1999 at 1A) and as "an invention that might be as important as the transistor or the electric light bulb." (USA Today, Apr. 9, 1999, at 1B); The *New York Times* proclaimed UWB "a technology that has the potential to make vastly more efficient use of the increasingly precious radio spectrum." New York Times, Dec. 21, 1998, at C1.

laws of physics establish the need for using extremely-wideband signals for such things as high resolution through-wall imaging systems, precision in-building location and tracking systems, and high processing gain, multipath resistant communications systems. TDC has demonstrated 30 different prototypes – that fill a void current technology does not cover – for products in the fields of radar, precision location and wireless communication, as well as products that fuse all three capabilities to provide even more innovative applications. TDC is pursuing prototypes and applications that can benefit law enforcement, military and public safety personnel, airport and residential security, construction and highway safety, as well as business and residential communications, surveying and tracking.

**Law Enforcement, Military & Public Safety Applications.** No technologies are more compelling or important than those that protect human life. UWB precision ranging radios and through-wall sensing radars will provide law enforcement and other public safety personnel with secure communications and improved information, enabling them to be more effective and better protected. UWB radar applications will allow officers to see movement behind walls and doors, visualize activity within buildings and detect breathing and other life signs in collapsed buildings and avalanches. GPRs are in use today, for example, to test the structural integrity of bridges and roadways, to locate buried utilities, and to find evidence in criminal investigations.[3] Short-range public safety command and control network radios, which provide geo-ranging and position information, can improve the response to hostile situations and rescue operations.

The military has used some forms of UWB for almost 30 years. These military applications supporting our national defense interests have helped to spur the growth of an entire commercial industry to develop further UWB technology. Former defense oriented laboratories funded by the Federal Government are now actively pursuing new

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[3] For example, the Federal Highway Administration has purchased a UWB road and bridge inspection system. Other federal agencies regularly use GPR for sub-surface mapping to locate objects and roadbed faults. Applications in development will provide a remarkable additional level of detail, accuracy and penetration.

applications of UWB technology. In addition, various university laboratories are investigating UWB technology because of its unique capabilities. There now exists the potential that these many unforeseen commercial applications will provide additional defense applications.[4]

**Aeronautical and Aviation Safety Applications.** Deployment of UWB systems that are compatible with safety-of-life systems will permit numerous applications of ultra-wideband radar and communications that can provide benefits in and around airports. These systems can enhance airport security measures by tracking personnel movements and controlling access to restricted areas for appropriate vehicles and persons. Also, for any air traveler who has lost luggage or been unable to change flights because luggage could not be retrieved, UWB promises relief through improved luggage tagging and tracking systems that can continuously identify and track luggage, as well as any vehicle or package.

Considerable discussion has focused on the possibility that UWB may create harmful interference with aviation use of GPS. TDC and others have repeatedly stated that this proceeding should ensure that UWB devices will not disrupt important safety of life systems, such as those operated by the FAA. If any UWB uses are found by the Commission to pose a credible risk of causing harmful interference to GPS systems by the FAA or the aviation industry, TDC fully expects that the Commission will not authorize those UWB uses.

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[4] UWB may play a key role in the most likely future combat environments – urban settings – where the capability to detect motion through walls and into buildings can provide additional awareness for combat soldiers enabling them to locate individuals and differentiate between friend, foe and civilian. UWB can locate stranded combat personnel and can be used to establish secure perimeters by creating instantaneous, fully portable electronic fences. Ground penetrating radar applications can detect mines.

UWB is also appealing in the military setting because it is resistant to jamming, which can occur with other technologies such as GPS. UWB signals are also far less susceptible to being intercepted and decoded or being used to locate the sending radio.

Nonetheless, one aspect of the UWB-GPS relationship should be noted and explored, as the UK and the US military are doing today.[5] Specifically, UWB has the potential for enhancing the performance and reliability of GPS and should be viewed as a complementary extension for GPS operations, as it is in the national interest to strengthen GPS. A cooperative atmosphere between the two industries would be conducive to ensuring that the technologies are compatible where their common goal is to provide the best available positioning information to the public and industry.

**Automotive Applications.** UWB has applications in automotive safety. For example, the technology can be used to determine the location of an automobile passenger at the moment of collision to allow for the safer triggering of the airbag. UWB also can be used as a "pre-collision sensor" that can determine the location of other vehicles while driving so as to alert the driver of dangerous situations.

**Subsurface Inspection Radars.** UWB radars can look into walls, structures and soil to determine their condition. Just as UWB can be used to assess the integrity of highways, runways and bridges; it can be used for building construction compliance, surveying and condition testing. Ground penetrating radar can locate buried matter, such as hazardous waste, unexploded ordnance, evidence in criminal investigations, fault conditions in man-made surfaces, or archaeological artifacts.

**Security Sensor Systems**. UWB-based proximity detection sensors would dramatically increase the level of protection that can be afforded to a home or other location. Range-gated radar to detect intrusion within a precise distance can be installed within or behind walls providing greater security. This can significantly reduce the frequency of false alarms by distinguishing between a cat and a cat burglar. At the same time, UWB sensor-based fence systems can offer effective security.

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[5] The UK has undertaken a study on how UWB can be used to enhance the Galileo satellite positioning system. *See* "New Communications Technology Projects Announced," British National Space Centre, available at <http://www.bnsc.gov.uk/latest/press_releases.html>. Similar work is underway within the U.S. military.

**Assistance for Physically-Disabled Individuals.** UWB also can provide navigation information at a size and at a cost that may have special applicability for those who are physically disabled. These devices can detect and alert the individual to sidewalk obstacles, subway door locations and provide enhanced, on the spot guidance to desired destinations.

**Wireless Communications Applications.** UWB technology can work synergistically with current technologies to provide operational features and to improve spectrum efficiency. For example, UWB-based wireless local area networks will improve these networks for offices and make them more affordable for homes, classrooms, and hotel rooms. UWB technology can also provide enhancements to mobile telephone service. In fact, TDC and mobile communications providers have been exploring ways in which UWB can be used to improve service.[6]

***The Communications Act Supports Authorization of UWB Services and Equipment***

As the Commission observed in its NPRM, Section 7 of the Communications Act of 1934 requires the agency to "encourage the provision of new technologies and services to the public."[7] This requirement, which was added to the Act in 1983, effectively

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[6] For example, a multi-mode portable phone can incorporate cellular and PCS capabilities for use in areas where only cellular and/or PCS can provide service. The same phone can also include a UWB capability for indoor use. The short range UWB capability can be set up in such a way that hand-off from the cellular/PCS network functions seamlessly with the traffic passed back into the cellular switch. As a call is handed off to UWB in offices, for example, the cellular/PCS channels with their comparatively higher power and longer range capability would become available for handling additional traffic. The phone would then shift from emitting a signal of up to 500 mW to transmitting at a level of approximately 50 μW – a reduction in output power by a factor of 10,000 or 40 dB. The same phone also could employ UWB technology to allow for precise indoor location to facilitate E911 or other services. Thus, UWB could provide users with capabilities indoors that would be difficult or impossible to accomplish using other location technologies such as GPS. As this illustration shows, UWB need not replace existing technologies; it can offer an advantage to both service providers and consumers by providing functionalities not available today.

[7] NRPM at ¶8, citing 47 U.S.C. § 157(a) (1998).

codified the ongoing policy that the Commission and the Congress recognized had delivered tangible public benefits. As the House Committee on Commerce stated:

> The Committee has long encouraged the FCC to foster the delivery of new services and technologies to the public in order to increase competition and promote diversity. Development of new electronic technologies and services has been, and will continue to be a significant factor in creating new jobs and providing U.S. leadership in the new world information era.[8]

Competition, diversity, domestic economic growth, and global leadership remain central to the Commission's policies and responsibilities, and the Congress and the Administration have continued to reiterate their support for these goals while reinforcing the Commission's responsibilities in this regard. The landmark Telecommunications Act of 1996 was described by the conferees as enacted to "accelerate private sector deployment of advanced telecommunications and information technologies" and the primary tools to achieve this goal were reduced regulation, new entry, and competition.[9] The '96 Act directs the Commission, for example, to forebear from imposing regulations where possible,[10] to periodically review and revise its rules to eliminate regulation,[11] to identify and remove barriers to competitive entry by entrepreneurs and small business,[12] and to achieve universal access to advanced communication services.[13]

Achieving efficiency of spectrum use is another important Commission policy goal.[14] UWB technology opens new avenues for efficient spectrum use through its ability

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[8] H.R. Rep. No. 98-356, at 6 (1983).

[9] S. Conf. Rep. No. 104-458, at 113 (1996).

[10] *See* 47 U.S.C. § 160 (1996).

[11] *See id.* § 161.

[12] *See id.* § 257.

[13] *See* Telecommunications Act of 1996, Pub. L. No. 104-104, 110 Stat. 56, 153 (1996).

[14] *See, e.g.,* 47 U.S.C. § 309(j)(3)(D) (directs the Commission to promote efficient and intensive use of the spectrum in designing competitive bidding systems); Balanced Budget Act of 1997, Pub. L. No. 105-33, 111 Stat. 251, 261 (1997) (instructs the Commission to promote efficient spectrum use in the 55 MHz identified for assignment); 47 U.S.C. § 922 (1992) (directs the Chairman, jointly with the Assistant Secretary of

to operate on a non-interfering secondary basis. Demand for new spectrum has exploded, and the resulting competition and innovation in products and services have led to dramatic increases in wireless voice and data applications. Growth in wireless use is far outpacing the communications market generally, which is good news for wireless companies and consumers only if the finite spectrum resource can be expanded to meet the supply challenge posed by this demand. Technological improvements to current user systems and traditional efficiency options, such as narrow channel spacing, will not be sufficient to keep pace with demand. At the same time, new technologies, such as Third Generation CMRS services, will add inexorably to the demands for new, reallocated spectrum. UWB offers an important variation on the successful spectrum-sharing regime established by the Commission in Part 15 and effectively increases the utilization of the most heavily used spectrum bands. UWB can meet important short-range communication and radar needs without requiring new allocations and without requiring existing providers to relocate.

UWB can help to reduce the ever-increasing demand for spectrum by utilizing otherwise fallow capacity for such applications as short-range indoor communications, radar, and tracking. By meeting these needs at signal levels so low as to be regarded as heretofore largely unusable for communications and radar, UWB will free up spectrum to meet needs that UWB cannot accommodate.

***UWB Should Not Face Greater Restrictions Than Unintentional Emitters Operating Under Part 15 of the Commission's Rules***

While the potential benefits of UWB have received considerable attention, questions have been raised concerning the potential for the technology to interfere with existing radio services, most notably safety of life services. As discussed in detail, *infra*, TDC believes that its UWB devices will cause the same amount or less interference than unintentional emitters operating under Part 15 of the Commission's rules. Under the

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Commerce, to promote efficient spectrum use, including technologies to promote shared spectrum use as a means to increase commercial access to spectrum).

Commission's rules, unintentional emitters at the same levels operating today may place energy into the restricted bands up to the Part 15 limits. There are billions of unintentional Part 15 devices in operation today from laptop computers to Palm Pilots to calculators. TDC respectfully submits that if UWB intentional emitters, operating at power levels equal to or below the Part 15 limits, cause the same amount or less interference than unintentional emitters to users of existing radio spectrum, then UWB devices should be permitted to operate under the same restrictions as unintentional emitters. The "intent" of the device should not matter, only its potential to cause harmful interference.

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From locating firefighters trapped in a burning building to delivering affordable Internet access within schools, UWB applications will improve public safety tools, expand communications access, create new businesses, increase spectrum efficiency and enhance America's global technological leadership. The NPRM cited many of these UWB applications, as well as the public benefits inherent therein. As important as these products and services are likely to be, the most beneficial potential of this technology is apt to lie in those applications unforeseen today. Given the wide range of applications already in development, it is evident that this is a technology with universal relevance and benefits. From the military to local law enforcement and rescue personnel to rural consumers, parents, doctors, teachers, the traveling public, and plant managers, UWB can improve how we live and work.

## TDC Responses to the Issues Raised in the NPRM

In the section below, TDC moves from addressing the public interest in UWB technology to addressing specific technical issues raised by the FCC in its NPRM and provide a general discussion of aspects of UWB technology that affect these issues. Generally, TDC has tried to address the specific technical issues in the order in which they appear in the NPRM.

### *General Characteristics*

The various technologies described by the term "ultra-wideband" are approaches to achieving unique performance characteristics. While the NPRM clearly identifies most of the different techniques used to generate these extremely wide bandwidths, along with the general characteristics of UWB waveforms it is critical to understanding UWB to have an appreciation of how UWB applications depend upon the particular operating frequencies.

#### Applications and Their Frequencies of Operation

As the FCC proceeds with its rulemaking, TDC believes it is important to recognize that different UWB applications operate best at different center frequency ranges. What may be optimal operating frequency ranges for one application may render another application inoperable. Figure 1 shows a collection of UWB applications and their particular operating frequency ranges.

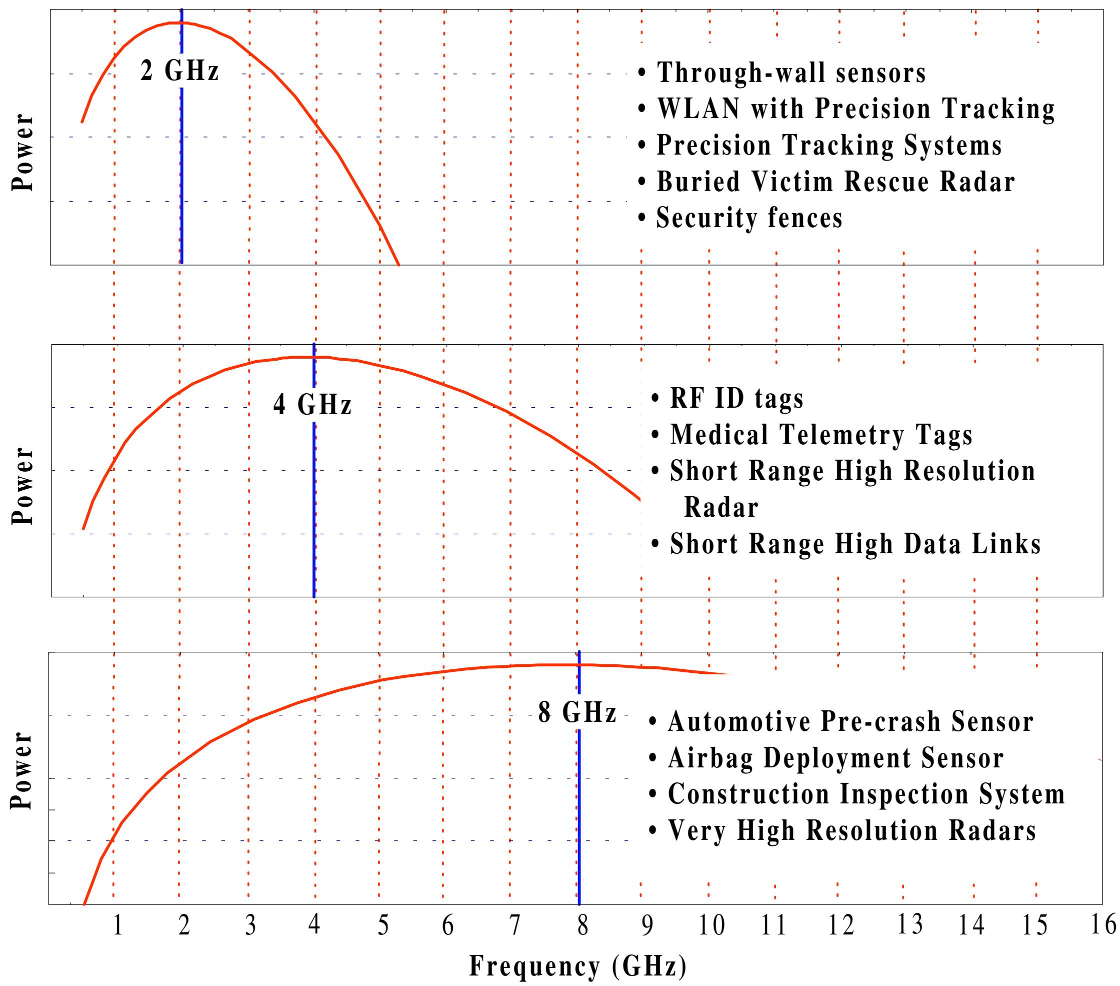


**Figure 1.** Applications of UWB and the Probable Bands of Operation.

TDC's work with through-wall sensing radars has shown that a center frequency of around 2 GHz is best because signals in this range can easily penetrate common construction materials.[15] Precision tracking systems usually operate at frequencies similar to those used by through-wall sensing systems. For example, a firefighter's tracking and communication system must be capable of penetrating fire stairwells.[16]

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[15] Attenuation through building materials such as brick and cement is greater at higher frequencies. At 2 GHz, propagation through concrete, even reinforced concrete is possible at Part 15 limits. However, penetrating concrete is much more problematic using higher frequencies at Part 15 levels. See Figure 2.

[16] *See id.*

In order to use UWB radar and positioning technology for public safety and other applications, TDC has determined that the following specifications can best be realized by permitting applications to operate with a center frequency of 2GHz:

1) The ability to penetrate typical construction materials to achieve a range of thirty feet or more,

2) The ability to resolve personnel standing shoulder width apart at a range of twenty feet,

3) An antenna array capable of fitting in a standard thirty inch door frame, and

4) Relatively low cost.

At 2 GHz, most common construction materials are relatively translucent as shown in Figure 2. At higher frequencies, attenuation through materials such as brick and cement block is greater; at much lower frequencies, screen mesh (as is common in stucco construction) causes significant attenuation (at 8 to 10 centimeters, the mesh is small enough to prevent low frequency signals from passing through). Operating at lower frequencies also allows timing tolerance, in terms of both drift and jitter, to be reduced significantly. This is critical due to the extreme temperature range over which the devices must operate. The ability to resolve personnel standing next to each other at twenty feet forces the system to have a half power beamwidth on the order of 11°. Assuming an array based system is used, a large fractional bandwidth and multiple look angles means the angular resolution is limited by the half power beamwidth (HPBW) of the array, which is dependent upon the center frequency. The minimum required center frequency can then be calculated by $f_c = c\, D_{array} \dfrac{HPBW}{50.8°}$. The array size will be limited to approximately 26 inches, therefore best frequency of operation for the prescribed criteria is 2.1 GHz.

Precision tracking systems can have operating frequency requirements similar to through-wall sensing systems. As an example, a firefighter's tracking and communication system must be capable of penetrating in fire stairwells. At 2 GHz, propagation through concrete, even reinforced concrete seems acceptable. However, at higher frequencies, it would be much more problematic, especially for the very low levels allowed by Part 15.

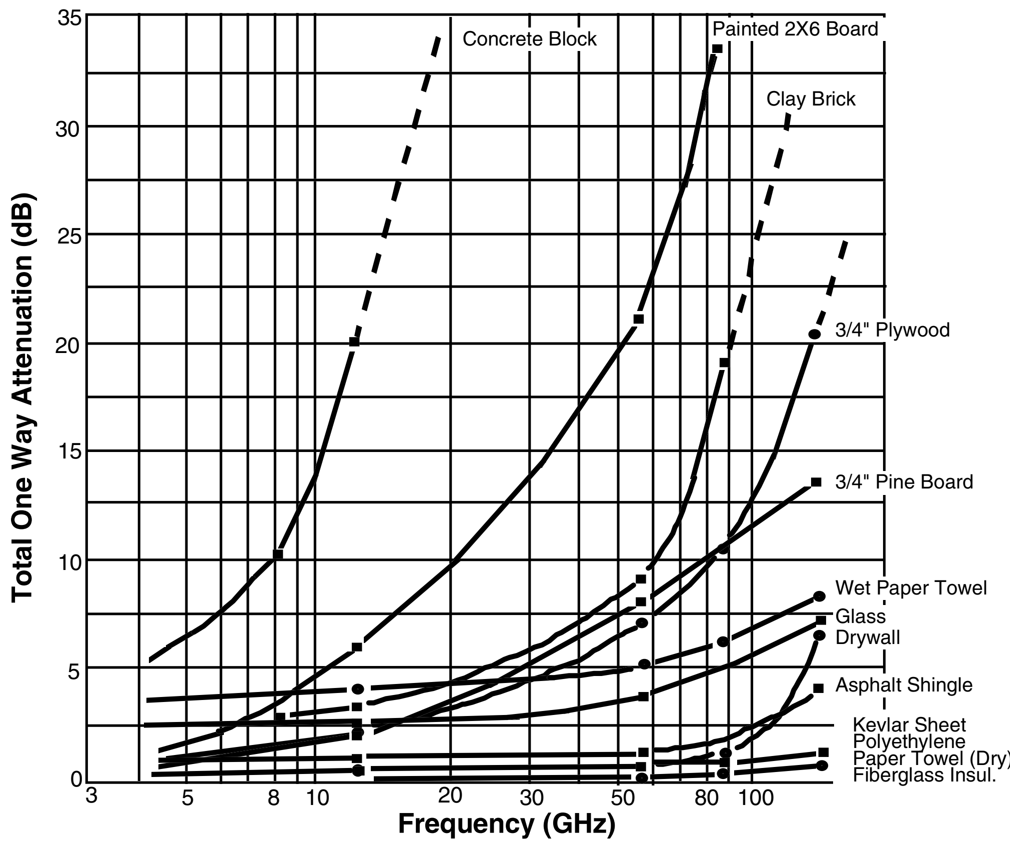


**Figure 2**. Losses of Various Building Materials.[17]

Many communications uses will often need to operate with a nominal center frequency of 2 GHz, particularly if the applications are also to take advantage of the precision location and tracking capabilities of UWB. The ability to fuse within one device not only high speed communications in support of voice and data, but also the capability for knowing the precise location of the person using the UWB device makes

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[17] Lawrence M. Frazier, "Radar Surveillance through Solid Materials", SPIE Photonics East Conference, Enabling Technologies for Law Enforcement and Security, Boston, MA Nov. 18-22, 1996.

this technology extremely beneficial. This benefit can be achieved by using the same signal for performing both communications and location. Such a capability will facilitate E911 applications within buildings, allow for the communications of important patient data and location information within treatment facilities as well as make it easier for hospitals to communicate with and locate personnel and major assets. Thus, not only can such communications applications benefit from the lower building material attenuation below 2 GHz, which becomes more of an issue as signals must pass through multiple walls within a building, but users can be provided with a precise location capability with no additional transmissions. To separate the communications from the location and tracking capability would add needless complexity, cost, size, and battery drain to the equipment.

There are also applications that require higher frequency operation. A prime example is automotive pre-crash sensing, with radically different requirements from a through-wall sensing system. The automotive pre-crash radar user requirements include:

1) Warning the driver in time for them to respond during a potential head on collision while both vehicles are travelling at a minimum 75 m.p.h.,

2) Angular resolution to distinguish the objects in the next lane (see Figure 3),

3) Minimizing the profile of the device to suit design and aesthetics, and

4) Minimizing the high cost of distributing RF cables.

To provide the driver with an adequate warning, the sensor must be able to distinguish adjacent cars at a range of 200 feet, which requires approximately 3.5° half-power beamwidth. This is a much tighter angular resolution, particularly since it must be housed in a physically smaller package as forced by economics, customer preferences, and area available on the automobiles. Following an approach similar to that previously described, an automotive pre-crash sensor would have a center frequency of at least 8 GHz in order to have an antenna aperture smaller than two feet. See Figure 3.

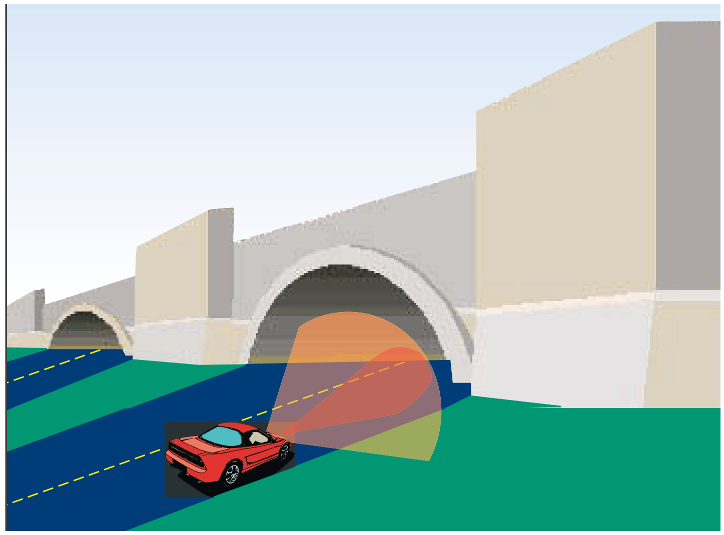

**Figure 3**. Automotive Pre-Crash Sensors Require Tight Angular Resolution.

A wide beam would mistake, for example, a bridge pier beside the road for an object in the lane. A narrow beam would not suffer from this deficiency.

Another example of a high performance radar is an air bag deployment sensor. The public has become painfully aware that airbags need more information about passenger positioning, to prevent deployment when unnecessary for inanimate objects or when the passenger's size or position may result in more harm when the airbag is deployed. This application is difficult enough that it is recognized that multiple sensor types will be required. The airbag sensor automotive pre-crash radar user requirements include: 1) ability to resolve the objects distance to approximately one inch, 2) angular resolution capable of distinguishing passengers sitting side-by-side, 3) ability to classify objects, 4) minimal device profile to suit aesthetics and available space, and 5) a way to minimize the high cost of RF cables. The range resolution drives the bandwidth to 6 GHz, which requires center frequencies above 6 GHz. This higher frequency operation aids the angular resolution requirement, while the large bandwidth aids in potential object classification.

These examples illustrate the wide variation in optimal frequency ranges for UWB applications. TDS urges the FCC to not place undue restrictions on specific operating frequency ranges to permit the public to take advantage of the full array of UWB applications.

**Applications and Their Operating Bandwidths**

Applications also demand specific operating bandwidths. While some have proposed very band-limited approaches,[18] which may be reasonable for their specific applications, many UWB applications will not function with tightly band-limited signals. For example, precision tracking of objects moving within buildings needs to use monocycle waveforms to achieve the highest precision. Figure 4 shows the impact of several walls and other clutter within an office building on a half-nanosecond UWB pulse.

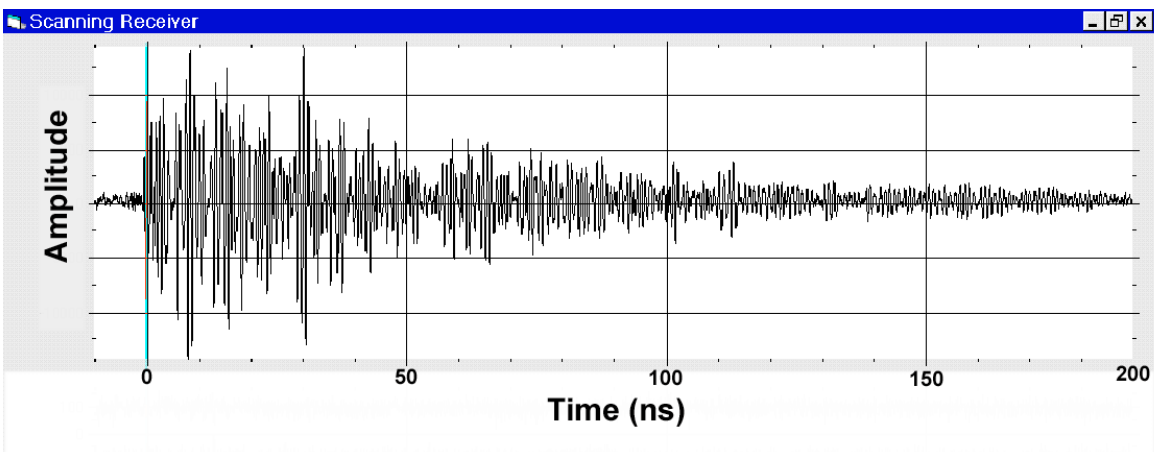


**Figure 4**. In-building Environment Creates Significant Scattering of RF Signals

Figure 4 shows how a single sub-nanosecond pulse reverberates through the environment and becomes spread out over a period exceeding 100 nanoseconds. In order for the precision tracking system to provide the most accurate position estimate, the first arriving pulse must be found. Using sub-nanosecond monocycle waveforms increases the speed at which a precision tracking system can search for the first arriving pulse because, as Figure 5 shows, monocycle waveforms are easily time resolved even when

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[18] *See* MultiSpectral Solutions, Inc. ("MSSI") NOI Comments at 6.

there is considerable multipath. Band-limited UWB or narrowband signals will have many zero crossings. For such signals, the impulse response becomes much more confusing, which creates significant time-of-arrival ambiguities.

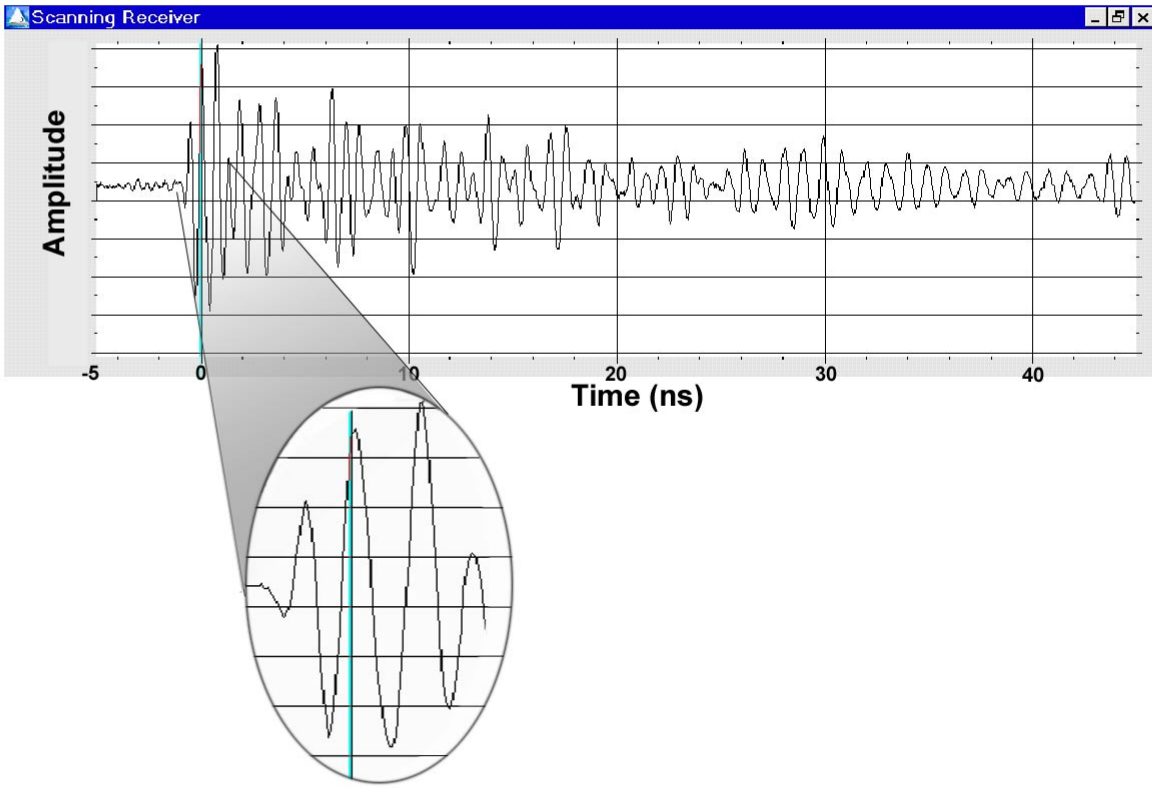


**Figure 5**. A Gaussian Pulse with a Time of Arrival Resolved to Approximately 3 ps.

With a short Gaussian pulse waveform it is possible to resolve the first arriving pulse with little ambiguity. In Figure 5, the first arriving pulse is magnified to show how easily it can be spotted even when there are lots of reflections of the signal. A system that uses a signal with many more zero crossings would have difficulty making a reliable determination of time of arrival. Missing a single zero crossing would lead, in this case, to an error of three inches. While three inches or even a foot may not seem like much, it must be remembered that concrete block walls may only be six to eight inches thick. Information on wall thickness can be critical to firefighters, engulfed in thick black smoke, trying to rescue a trapped individual and get out of a building. In some applications such as the control of cutting tools, it can mean the difference between normal safe operation and the loss of a hand. Therefore, TDC urges the FCC to not impose band-limited requirements.

Gaussian monocycles are a waveform used extensively by the UWB industry. The spectral envelopes for three different ultra-wideband emissions generated by Gaussian monocycles are shown in Figure 6. The leftmost waveform has its peak emission at 2 GHz, the next at 4 GHz, and the third has its peak emission at 8 GHz. As Figure 6 shows, there are no sharp band-edges or steep roll-off rates with these emissions. UWB signal design generally avoids sharp edges or steep roll-off rates because waveforms with these characteristics have significant losses in radar resolution, distance measurement accuracy, interference rejection, and processing gain.[19]

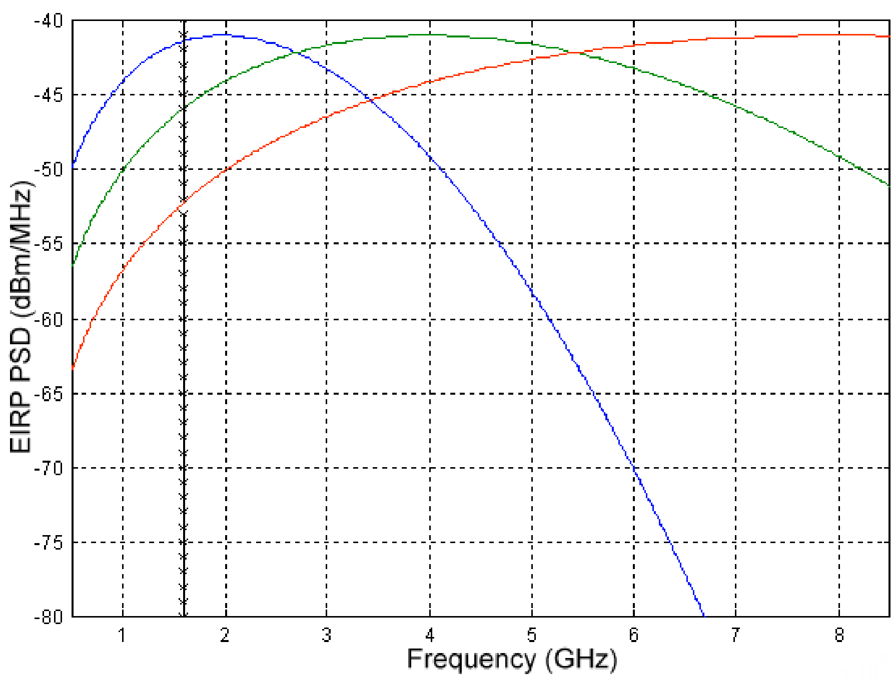


**Figure 6.** Spectral Envelopes of Three Gaussian Monocycle Pulses

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[19] The impact of sharp edges in the frequency domain was extensively documented in the responses to the UWB NOI. *See* TDC NOI Comments, Appendix D; Zircon Corp. NOI Comments; Interval Research NOI Comments.

TDC is concerned that the Commission is considering a regulation that requires a significant reduction in field strength below 2 GHz. As an initial matter, the Commission's longstanding experience with emissions from digital devices and other unintentional and incidental radiators at levels equal to or greater than the general limits in Section 15.109 of the Rules suggests that such additional protection is not needed.[20]

There are two implications of these waveform characteristics and any regulation that establishes a large step change in allowable field strength, *e.g.,* 12 dB decrease in field strength for emissions below 2 GHz:

1) Applications such as precision ranging that require the use of an undistorted monocycle waveform would be forced to use a signal with a significantly higher peak or center frequency. As Figure 6 shows, even a Gaussian monocycle with an 8 GHz peak frequency is not 12 dB down at 2 GHz, and is barely 12 dB down at the GPS L1 frequency. Thus, for the applications that require a clean monocycle, such a regulation would force UWB equipment designers to move to a frequency with dramatically different – and potentially unsatisfactory – propagation characteristics.

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[20] As discussed, *infra,* TDC submits that the Commission should find that UWB emissions are generally equivalent to the emissions emitted by many digital devices. Indeed, the Commission's experience with compliant digital devices has shown a notable paucity of reported interference complaints. Moreover, TDC notes that the Commission has rejected calls for the suppression of emissions in the GPS bands by more than –70 dBW/MHz, a limit that is slightly less severe than the Part 15 general limits. *See* Service Rules for the 746-764 and 776-794 MHz Bands, and Revisions to Part 27 of the Commission's Rules, WT Docket No. 99-168, *Memorandum Opinion and Order and Further Notice of Proposed Rulemaking*, FCC 00-224 (rel. June 30, 2000) at ¶ 30; Service Rules for the 746-764 and 776-794 MHz Bands, and Revisions to Part 27 of the Commission's Rules, WT Docket No. 99-168, *First Report and Order*, 15 FCC Rcd 476, 524 (2000); AirTouch Satellite Services US, Inc.; Application for Blanket Authorization to Construct and Operate up to 500,000 Mobile Satellite Earth Terminals Through the GLOBALSTAR Mobile Satellite System, 14 FCC Rcd 17328 (1999).

2) If, on the other hand, the waveform is filtered below 2 GHz, the characteristics inherent in UWB signals will be lost for the pulse shape will be dramatically altered. Also, assuming that the signal can tolerate the waveform distortion caused by filtering, the UWB signal will emit less total power. Notching removes power at a particular frequency, but because of the fixed field strength limitation UWB emitters are unable to increase their power at other frequencies to make up for this loss. Thus, in this case, not only would there be a potentially critical loss in performance due to waveform distortion, there would also be less signal power.

In sum, any limits on UWB emissions imposed in order to provide additional interference protection to specific services should be based on a solid technical record and the FCC should accord as much flexibility as possible to UWB system designers to retain the beneficial aspects of UWB technologies.

**Regulatory Treatment**

TDC agrees that, at this time, the most appropriate place within the current rule structure to allow for low power UWB systems is within Part 15 of the FCC rules on an unlicensed basis. Part 15 regulation would allow this new technology to be used for many low-power short-range applications. The FCC has had more than two decades of history following this rule part to observe whether the general emission limits for digital devices are low enough to protect against harmful interference, and also to see if the philosophy of encouraging spectrum sharing has had a positive economic impact. The FCC's well-reasoned experiment with Part 15 has shown that its regulations protect against harmful interference and allow for the introduction of new wireless technologies and applications (*e.g.,* spread spectrum systems, U-NII and millimeter wave devices, as well as billions of digital devices that place emissions in many parts of the spectrum).

***UWB Definition***

TDC supports the FCC's use of the DARPA definition for UWB.[21] However, the Commission should consider making the definition based solely on a percentage of relative or fractional bandwidth. TDC does not believe, however, that all devices with bandwidths of 1.5 GHz or more should be characterized as UWB devices even where the nominal frequency exceeds 6 GHz. TDC submits that most of the benefits of UWB (*e.g.,* multipath immunity) only come from having very few cycles within the pulse envelope, not the duration of the pulse envelope itself. TDC explains its reasoning for this position in the following section on relative bandwidth.[22]

**Use the Relative Bandwidth Definition**

Figure 7 shows two different pulses. Both are confined to the same Gaussian envelope, but at two drastically different center frequencies. Since both have the same pulse envelope, they have the same bandwidths. However, these pulses have very different fractional bandwidths. The pulse with the higher center frequency will not have the same physical properties that the pulse with the lower center frequency – it will not have the same resistance to multipath, for example, nor the same propagation characteristics. In the presence of a lot of multipath, the "dashed-line" pulse will be much more easily resolvable then the "solid line" pulse.

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[21] *See* NPRM ¶ 21. *See also* Assessment of Ultra-Wideband (UWB) Technology, OSD/DARPA Ultra-Wideband Radar Review Panel, R-6280, Defense Advanced Research Projects Agency, July 13, 1990; James Taylor, *Introduction to Ultra-Wideband Radar Systems*, at 2 (1995).

[22] The UWB NOI comment from XtremeSpectrum also has good discussion of this rationale. *See* XtremeSpectrum, Inc. NOI Comments at 5.

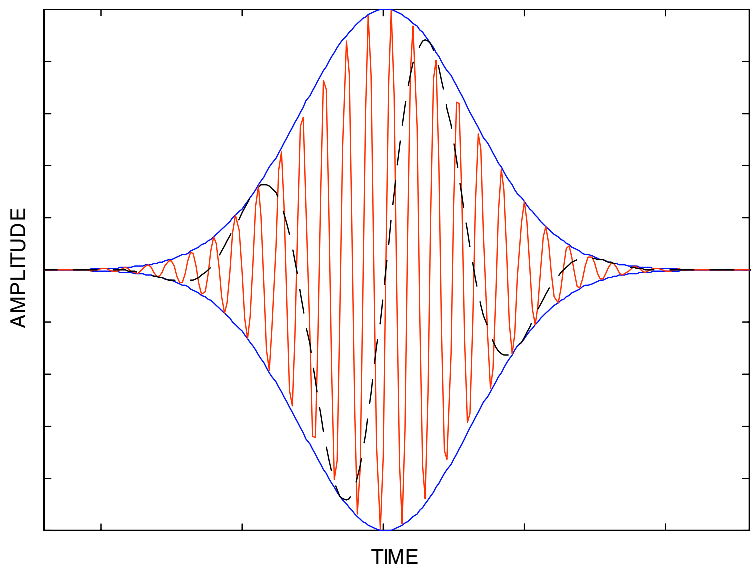


**Figure 7**. Two Gaussian Pulses with the Same Bandwidths, but Dramatically Different Center Frequencies

To illustrate the difference in multipath resistance between short pulses with few cycles and pulses with many cycles, Figures 8 and 9 show conceptually the impact of waveforms with equal center frequencies, but different bandwidths. Figure 8 shows a waveform with a 10 GHz center frequency and 10 GHz of bandwidth – a waveform with only two cycles, while Figure 9 shows a waveform with a center frequency of 10 GHz and 1.5 GHz of bandwidth – a waveform with many cycles. Under the definition proposed by the FCC in the NPRM, both of these would be UWB signals. However, in the presence of multipath reflections, the system with only 1.5 GHz of bandwidth would suffer from significant fading.

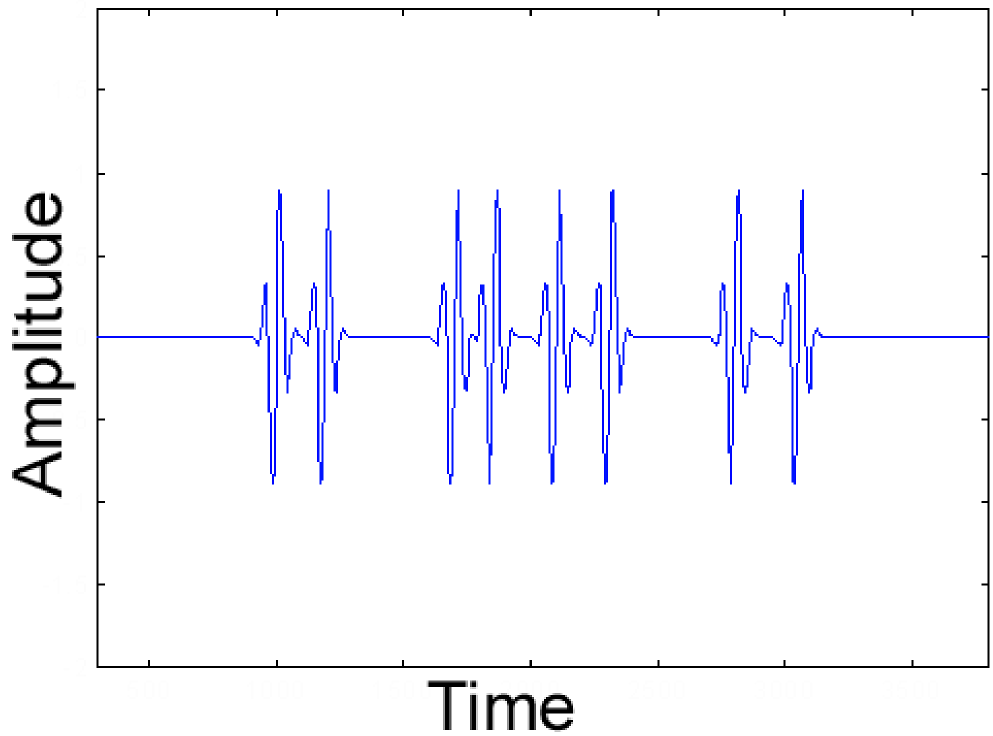


**Figure 8**. Eight 10 GHz Center Frequency Pulses with 10 GHz Bandwidth Representing The Impact Of Multipath.

As shown in Figure 8, due to the short pulse duration, each pulse remains independently time-resolvable and immune from multipath fading.

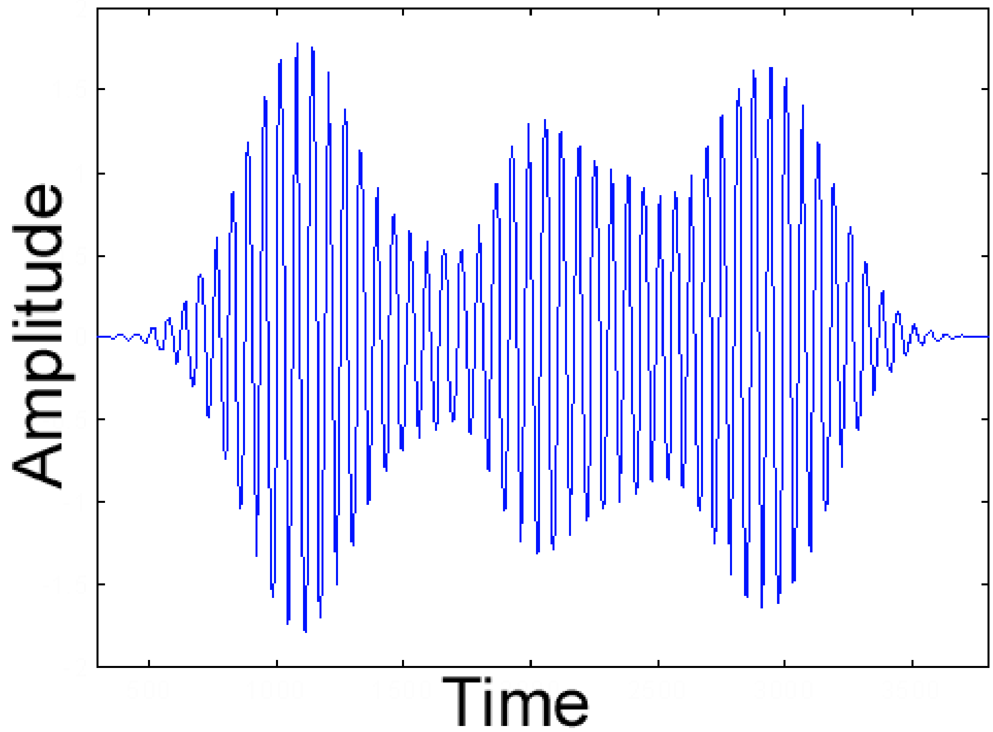


**Figure 9**. Eight Overlapping Pulses with 10 GHz Center Frequency and 1.5 GHz Bandwidth.

These pulses in Figure 9 would experience significant multipath fading due to the multiplicity of cycles in the base pulse.

TDC has conducted extensive in-door propagation experiments.[23] This work shows that the situation depicted in Figure 8 is much better than is typical for an in-building environment. Many facilities have significantly more clutter. If the definition of UWB signals is to include only those signals with true UWB characteristics, the FCC should define UWB solely in terms of relative bandwidth with the upper and lower

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[23] *See* P. Withington, R. Reinhardt and R. Stanley, "Preliminary Results of an Ultra-Wideband (Impulse) Scanning Receiver," IEEE MILCOM '99, Atlantic City, NJ, Nov. 1999; M. Win and R. A. Scholtz, "Energy Capture vs. Correlator Resources in Ultra-Wide Bandwidth Indoor Wireless Communications Channels" IEEE MILCOM '97, Monterey, CA, Nov. 1997.

frequencies defined as the 10 dB down points. In short, relative bandwidth – and not bandwidth alone – provides the most notable benefits of UWB technology.

**Use of the -10 dB Bandwidth**

TDC agrees with FCC's proposal to use the -10 dB bandwidth for the definition of an UWB device, since it is extremely difficult to reliably measure the -20 dB bandwidth.[24] This is discussed in detail in a later section on UWB measurement.

**Stepped and Swept Frequency Systems**

TDC agrees with the Commission's assessment that there is not a lot of information on stepped and swept frequency systems. While aware of some swept and stepped frequency approaches, TDC is not familiar with these techniques. Based on TDC's limited knowledge of these systems, it appears that these systems could avoid the restricted bands while remaining adequate for their applications. If this is indeed the case, such devices can already gain approval under the Part 15 general limits since they would not have fundamental emissions within the restricted bands.

***Frequency Bands of Operation***

TDC remains in full agreement that the licensed services, especially, safety-of-life applications, must be protected against harmful interference. TDC, along with the Executive Committee and many individual members of the UWB Working Group, submitted a joint policy statement recognizing this principle and agreeing to implement whatever mitigation techniques are necessary if harmful interference is found.[25]

The Commission clearly understands that each application of UWB has its optimal band of operation and is attempting via this NRPM to create rational emission

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[24] TDC discusses this position at length in the Measurement Procedures section of these comments, *infra*.

[25] *See* UWB Working Group Executive Committee joint statement, ex parte presentation, Docket 98-153, Jan. 14, 2000.

limits in these bands. However, as shown in the discussion on the implications of Figure 6, regulations can threaten the deployment of many viable UWB systems even if that is not the intention.

The Commission stated that it contemplates a rule requiring that through-wall sensing systems have a switch that prevents them from operating when not in contact with a solid object.[26] During TDC's discussions with public safety personnel it became clear that this would make the system unusable in many circumstances. Law enforcement personnel believe that some situations would require placing through-wall sensing radars near the target area, with the device operated from a standoff range. Requiring them to keep the device in physical contact would place individuals operating the radars in a life-threatening position. Moreover, with regard to sensing for people buried in collapsed buildings, there may not be flat surfaces against which to place the radar and, thus, it may not be possible to depress the switch when it needs to be operated.

The Commission also inquired about the feasibility of incorporating into through-wall sensing systems to be used by law enforcement and public safety personnel, some sort of automatic power control to reduce power to the minimum amount necessary.[27] TDC would advise against such a requirement because many situations may involve multiple targets at varying distances within a given area, such as a room, and automatic power control could lock the radar system at a power level below a level that may be needed to find a new target entering the room.

Through-wall sensing systems have benefits for consumers and should not be limited to just law enforcement and public safety organizations. While the most sophisticated versions of UWB through-wall sensors are likely to be used by these groups, similar technology can be used as high performance security sensors for commercial and residential applications. Today's Doppler radar sensors are not range gated; consequently, they are subject to false alarms when large targets outside of the

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[26] *See* NPRM ¶ 26.

[27] *See id.*

intended operating range cause the sensor to detect motion. With high performance UWB sensors, the range gate can be controlled to within a few inches to reduce false alarms.

**Operations below 1 GHz**

TDC agrees with the Commission that the only likely UWB systems with nominal center frequencies below 1 GHz are ground penetrating radars and perhaps some specialty radars. TDC believes that the Commission may not even need to have any special licensing here, since GPRs are operated by trained professionals, their use is limited, and they have proven over the last few decades to have tremendous value to the public and the government apparently without any reports of causing harmful interference.

**Operations above 2 GHz**

TDC agrees with the Commission's proposal not to place restrictions on UWB devices operating with nominal center frequencies above 2 GHz. The NPRM notes that UWB systems could generally operate with nominal center frequencies above 2 GHz without causing harmful interference. This is consistent with the analysis and testing that TDC has performed in house, especially regarding the 2.4 GHz bands that have become increasingly popular for wireless LANs, and cordless phones (both direct-sequence and frequency-hopping spread spectrum systems).

**Operations in the 1 GHz to 2 GHz Band**

The band of greatest concern, not only to the government, but also to TDC, is between 1 GHz and 2 GHz. TDC applauds the FCC's decision to consider allowing UWB emissions into this band should the planned testing demonstrate compatible spectrum sharing. TDC recognizes that much of the FAA's most sensitive equipment lies in the bands between 960-1660 MHz; a band that includes all three GPS frequencies. Thus, should the need be demonstrated for additional attenuation of UWB signals to protect safety-of-life bands, 1660 MHz is a more rational limit than 2 GHz. This would provide additional protection to safety of life services without imposing an overly restrictive guardband.

Unlike the band below 1 GHz, TDC does see a need for emissions into the spectrum between 1 GHz and 2 GHz, i.e., nominal center frequency around 2 GHz. At the incredibly low power levels contemplated by the proposed rules for UWB, most of the applications will be in-building systems and propagation is better in this range of frequencies than at higher frequencies. (It should be recognized that even if the UWB nominal frequency were shifted upward, a significant proportion of the miniscule amount of energy would still be present in this band.) Filtering of a UWB signal reduces total power and there is no way to gain that lost power back except to move to a significantly higher frequency of operation. As discussed above, such a shift is not feasible for many applications.

When TDC first began discussions with the FCC on UWB, it was natural to use the existing general limits because they were working. In the past two decades during which the current limits have been in force, the number of unintentional devices has exploded. In addition, modern personal computers have become more like intentional UWB emitters in the 1 to 2 GHz band. Because the clock rates inside many of these digital devices are now above 1 GHz, engineers have resorted to dithering the clock signals to smear the spectral comb lines of the emissions so that the devices can comply with the rules.[28] Thus, as a result, rather than having very narrow spectral lines corresponding to multiples of their clock frequencies, these lines are being broadened so their power spectral densities are lower in a given measurement bandwidth.

***Further Testing and Analyses***

TDC plans to provide the Commission with studies of the interference potential from UWB devices on several systems by October 30, 2000, including a major test of GPS susceptibility being conducted by the Applied Research Laboratory at the University

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[28] *See* Chris Arcus, *Spread spectrum reduces EMI problem*, EE TIMES, Jan. 18, 2000.

of Texas at Austin. Additionally, the Commission is monitoring the testing being conducted by NTIA and the Stanford University / Department of Transportation (DoT) to examine the potential interference to GPS and other receivers.[29] TDC provided NTIA and Stanford / DoT with detailed comments regarding their respective test plans.[30] TDC understands that many of these testing efforts will produce large volumes of test data and suggest that the Commission setup a special place on its website to either host the data, or at a minimum, provide a hyperlink to other Internet locations where the data are stored.

***Emissions Limits***

**Average and Quasi-peak Emission Levels**

For frequencies above 2 GHz, TDC agrees with the Commission's position that the Part 15 general emission limits are appropriate for UWB operations. However, for frequencies below 2 GHz TDC strongly disagrees with the tentative proposal of a 12 dB step down in the allowable electric field strength. The Part 15 general limits have shown to be adequate to protect against harmful interference. Certainly, the UWB community wants to protect the restricted bands, but this goal can be met with reasonable emission limits that do not unnecessarily limit the benefits that UWB operations can offer.

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[29] Testing conducted by the Applied Research Laboratory of the University of Texas at Austin is available at <http://sgl.arlut.utexas.edu/asd/Cure/testplan.html>. Information regarding the testing being conducted by the NTIA is available at <http://www.ntia.doc.gov/osmhome/uwbtestplan/gpstestfr.htm> and information on NTIA testing of non-GPS federal systems is available at <http://www.ntia.doc.gov/osmhome/uwbtestplan/>. A copy of the test plan developed by Stanford University for the DoT is available directly from DoT staff at: Office of the Secretary, Radionavigation & Positioning Staff, P-7, Room 10315, 400 Seventh Street SW, Washington DC, 20590.

[30] Copies of the comments TDC submitted to NTIA in response to its GPS Test Plan are available at <http://www.ntia.doc.gov/osmhome/uwbtestplan/GPScomments/timedomain.html>, and the comments TDC submitted to NTIA on the federal systems testing are available at <http://www.ntia.doc.gov/osmhome/uwbtestplan/comments_on_ntia_plan.htm>. Copies of the comments TDC submitted in response to the Stanford University / DoT GPS test plan available on the DoT's Document Management System website at <http://dms.dot.gov/>, via searching under Docket OST-2000-7538-2.

Billions of emitters currently operating in the spectrum below 2 GHz at the general Part 15 limits (*i.e.* class B limits for digital devices) are not causing harmful interference. Additionally, as computer technology advances, the clock and edge rates are moving higher in frequency. Indeed, there are now a significant number of digital devices that have emissions between 1 and 2 GHz. If this were a serious problem it would suggest that the unintentional radiator limit should be changed – a modification that would have a broad impact on the computer and other industries.

Requiring a 12 dB decrease in the allowable field strength limit below 2 GHz will end up protecting users that do not fall into restricted bands. Such a proposal will, in effect, change the Part 15 general limit as well, which will have a broad impact on all electronic device manufacurers. Intentional radiators (as well as unintentional and incidental emitters) can already emit in this area of the spectrum without special permission, new rules, or reduced emissions. Lacking a justification based on results of tests performed using accurate models of real-world scenarios, UWB devices should not be treated differently. As the Commission noted in the NPRM, interference testing will help to better quantify the impact of UWB signals within the restricted bands below 2GHz.

The FCC asks whether the proposed limits below 2 GHz should be applied to GPRs and through-wall radars.[31] At this time TDC firmly belives that general Part 15 unintentional radiator limits are appropriate for these applications as well as other wireless communications applications as discussed above.

**Equivalence of Intentional and Unintentional Emitters**

TDC disagrees with the discussion in the NPRM that attempts to explain the differences between intentional UWB emissions and unintentional emissions from digital devices.[32] Many of these digital devices produce radiated waveforms that are very

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[31] *See* NPRM ¶ 39.

[32] *See id.* ¶ 40.

similar to UWB emissions being proposed for new rules, and in many cases it is not possible to tell which is which.[33] The FCC states that unintentional radiators "generate emissions on only a few narrow frequencies that approach the general limits; the other emissions are well below these limits."[34] To the contrary, many personal computers and workstations, from the most common and name brand manufacturers, have emissions near the limit at more than just a few narrow frequencies.

Modern digital devices have emissions from all of the internal clocks, and other switching processes. As clock rates approach 1 GHz, logic switching speeds keep pace with the result that the emission spectrum of digital devices continues to move higher in frequency. Clock harmonics (and possibly fundamentals) are produced as well as significant broadband energy from the overlapping fast switching edges such as busses and high speed interfaces.[35] For example, some high end graphics stations are capable of switching the pixel cells of a high resolution display monitor on and off at extremely high rates. As a result, the video card device drivers produce very broadband "hash" that is related to video content rate of change. These systems are permited to radiate this "hash" or noise at Part 15 Class B limits or, even the higher, Class A limits. This hash appears as broadband noise and when measured with a wideband measurement system exhibits peak levels that can exceed the proposed peak limits for UWB devices. Further, currently available processors for desktop computers operate at frequencies of 1 GHz, which involves a one nanosecond period and is very comparable to the pulse duration of many UWB devices.

A one nanosecond pulse with a PRF of a hundred megahertz or a thousand megahertz can generate emissions covering several gigahertz, which could be near the Class A limit and still be compliant and legally marketed with no concern as to location

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[33] *See* TDC NOI Comments, Appendix E; Interval Research NOI Comments, Exhibit 4.

[34] *See* NPRM ¶ 40.

[35] As mentioned earlier in these comments, many manufacturers are reducing their measured emissions by using spread spectrum techniques to widen and reduce the

or aggregation effects.[36] It should also be noted that with clock periods of one nanosecond, the leading and trailing edges of these pulses have rise and fall times that are likely in the range of one hundred picoseconds or less. However, regardless of the number of spectral lines that are near the limit, the real point is that these spectral lines can fall *anywhere* within the spectrum, including within the restricted bands or commercially licensed bands.

As evident from the examples above of digital devices' internal clocks, high-end graphic stations, and processors for desktop computers, unintentional emitters may place the same amount or greater amounts of energy into the restricted bands between 1 and 2 GHz. TDC respectfully requests that the FCC carefully consider whether intentional emitters placing the same amount or less energy into these restricted bands should be held to a higher standard.

**Peak Emission Limits**

TDC agrees with the Commission that the peak emissions of UWB systems may need to have limits. Without peak limits, systems theoretically could be developed that meet the average limits, but have very low pulse repetition frequencies and, therefore, have enormous pulses. Any peak limits should be established to protect against interference. Accordingly, the limit(s) and the measurement technique(s) should be representative of common victim receivers.

For example, in reviewing the 50 MHz peak emissions limit, it is not clear how a bandwidth of 50 MHz and a limit of 20 dB are indicative of interference potential to typical receivers. The NPRM provides no justification for these values, and no specifics detailing the filter specifications and how this relates to a victim receiver characterisitics. It would seem that the Commission would want to correlate the limit with receiver characterisitics such as typical dynamic range, or the acceptable one decibel compression

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maximum levels of the spectral lines with the result that a wider band of frequencies will be affected by clock emissions.

[36] Class A equipment presumably would be in commercial and industrial settings.

point for a victim receiver. These characteristics are the limiting factors for maintaining linear performance in the presence of large peak power signals. For instance, many receivers have bandwidths on the order of 10 MHz, while GPS receivers may have bandwidths on the order of 20 to 30 MHz. Also, most receivers can easily obtain dynamic ranges of 90 dB.

Using the relationships developed by WinForum, NTIA, and others for the impulse response of a filter as a function of PRF and filter bandwidth, for a UWB system with a 1 MHz PRF, the peak-to-average ratio in a 50 MHz bandwidth will be 20log(50MHz/1MHz) which equals 34 dB; and the peak level in a 30 MHz bandwidth will be 20log(30 MHz/1 MHz) which equals 29.5 dB. Requiring a 20 dB limit of peak over the average within a 50 MHz bandwidth limit will force UWB manufacturers to operate at higher PRFs than may be needed for the specific application or to reduce their average radiate power drastically.[37] The peak over a 50 MHz bandwidth compared to the average limit for a 10 MHz PRF system would be 24 dB (*i.e.,* 10log(10MHz/1MHz) + 20log(50 MHz/10 MHz)); for a 20 MHz PRF system it would be 21 dB (*i.e.,* 10log(20MHz/1MHz) + 20log(50 MHz/20 MHz)), and for a 50 PRF MHz it would be 17 dB (*i.e.,* 10log(50MHz/1MHz)). Therefore, to meet this peak limit while operating at the average limit, the PRF would have to be in excess of 20 MHz. This would have an impact on many UWB applications, such as radars, which are designed for lower PRFs in many cases due to the relationship between range and PRF. Unless justified by test results, this seems contrary to the Commission's stated goal, which is to develop limits and procedures that protect potential victim receivers and at the same time provide the UWB community with the maximum flexibility to design their products to meet the requirements for the application. TDC is studying this issue in detail and at this time our belief is that a more appropriate limit may be 30-50 dB in a 30 MHz bandwidth, which is also basically consistent with the bandwidth proposed by WINFORUM in response to the NOI.

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[37] *See* NPRM ¶ 43.

The “absolute peak limit” proposed by the Commission in paragraph 43 triggers similar questions. The limit of 60 dB for the absolute peak above the average limit seems to be more reasonable than the peak limit above in that a UWB system with a 1 ns pulse width and 1 MHz PRF can meet the 60 dB limit. However, in any event, the question remains as to the meaning of this value. The absolute peak will only be relevant to receivers that have a bandwidth wide enough to receive the entire UWB spectrum. The only receivers with bandwidths on the order of UWB emissions in their operating bandwidth are UWB receivers, which are designed to receive the right UWB signal and to contend with many other transmitters both licensed and unlicensed that will have output power levels much higher than the other UWB transmitters. Such a limit is not needed to protect non-UWB receivers.

Further, laboratories providing certification data to the Commission generally will not have the requisite equipment and would therefore be unable to conduct such measurements. One can postulate that the equipment could always be rented; however, this equipment is complex and requires a knowledgeable operator (an attribute not commonly available without a great deal of experience in operating today’s modern instrumentation) or the data is very unreliable. Moreover, time domain measurements are subject to the time domain characteristics of the measurement system and it is extremely difficult to compensate time domain measurements for the phase dispersion caused by the measurement antenna, amplifier, and cables. Therefore, TDC sees little value in regulating the absolute peak power.

**AC Power Line Conducted Limits**

TDC agrees with the FCC's conclusion in paragraph 45 that the "existing limit in 47 C.F.R. Section 15.207 for controlling the amount of energy permitted to be conducted onto the AC power lines is a reasonable starting point for establishing standards until additional experience can be gained with this equipment." UWB operations are no different than other Part 15 devices in this area, and, with good engineering practices, UWB manufacturers should be able to meet this limit.

**Cumulative Impact**

TDC agrees with the Commission's Technology Advisory Council, Spectrum Management Focus Group, which examined four technical papers on aggregate emissions and concluded that the noise floor of a receiver will be set only by the closest UWB transmitter only.[38] The aggregate impact of UWB systems is also being measured as part of the ARL:UT testing effort, noted *infra*. From these tests, more data will be made available for comments in the future regarding the cumulative impact. In general, for analysis purposes it is critical to remember several real world (*i.e.,* "operational scenario") factors:

- **Propagation losses**. Many UWB applications are focused upon in-building usage where the propagation losses will be greater than in free space. Moverover, the farther away a transmitter is, the more likely that it is transmitting through multiple walls which adds additional attenuation over signals from the transmitters that are close by.
- **Operational duty cycle**. This accounts for the fact that many of the UWB transmitters will not be on or transmitting all of the time. For instance, a wireless link may only transmit when necessary. Also, an asset tracking tag on a package or on luggage may only transmit once a minute, or once every 15 minutes, to indicate its ID and location.
- **On/Off time duty cycle**. This is the duty cycle within the on time discussed above. For instance, the RadarVision1000, a prototype device submitted under the TDC waiver, sends out time modulated pulses approximately every 200 ns with a signal "bursting" of 4 ms on and 4 ms off.
- **Antenna polarization**. This factor accounts for the rotation and positioning of the antennas. Different UWB applications will require different polarizations and must be accounted for when designing an aggregate model.

[38] *See* NPRM ¶¶ 46-47.

- **Ambient noise**. The noise floor of a receiver will be set by its system noise floor plus the level of the ambient noise that is producing the highest emissions within the receiver's passband that are incident on the receiver's antenna, whether the source of that ambient noise is a UWB transmitter or another emitter.
- **Victim receiver antenna gain and pattern**. Antennas with gain provide isolation from some of the ambient signals.

These system and environmental factors will help to ensure that a cumulative analysis will accurately model the impact from multiple UWB transmitters.

***Measurement Procedures***

**UWB Signal Measurements**

TDC believes that in order to measure accurately the frequency and time domain characteristics of UWB signals the measurements should be performed at one meter and preferably in an anechoic chamber, especially for time domain measurements. Analysis and measurements indicate that accurate characterization of the UWB signal cannot be performed at three meters due to narrowband and broadband ambient electromagnetic signals, receiving system sensitivity, and reflections. ANSI C63.4-1992, paragraph 8.2.4, allows for closer test distances and for measurements to be performed in an anechoic chamber for frequencies above 1 GHz. Comparisons of frequency domain measurements of an UWB device at an Open Area Test Site ("OATS") at both one and three meters are shown in Figures 10 and 11. The plots reveal the measurement issues associated with the one and three meter test distances, as well as measurements made at an OATS with ambient signals in the same frequency range as the UWB signal.

For the measurements shown in Figures 10 and 11, a time modulated UWB signal was used. The measurements shown are with a resolution bandwidth (RBW) of 1MHz and video bandwidth (VBW) of 1 kHz to represent the current Part 15 technique and proposed average technique for UWB. These measurements were compared with mathematically predicted electric field power spectral densities (using the measured spectrums of the subsystem components).

It is clear from the figures that measurements at 1 meter have much better sensitivity and are useful for determining the 10 dB bandwidth points. The following section discusses in detail the reasoning behind the necessity for 1 meter measurements relating to the receiver sensitivity for spectrum analyzers. TDC agrees with the FCC that the antenna is an integral part of UWB systems and that ALL measurements must be made with the antenna designed to be used with the UWB device.

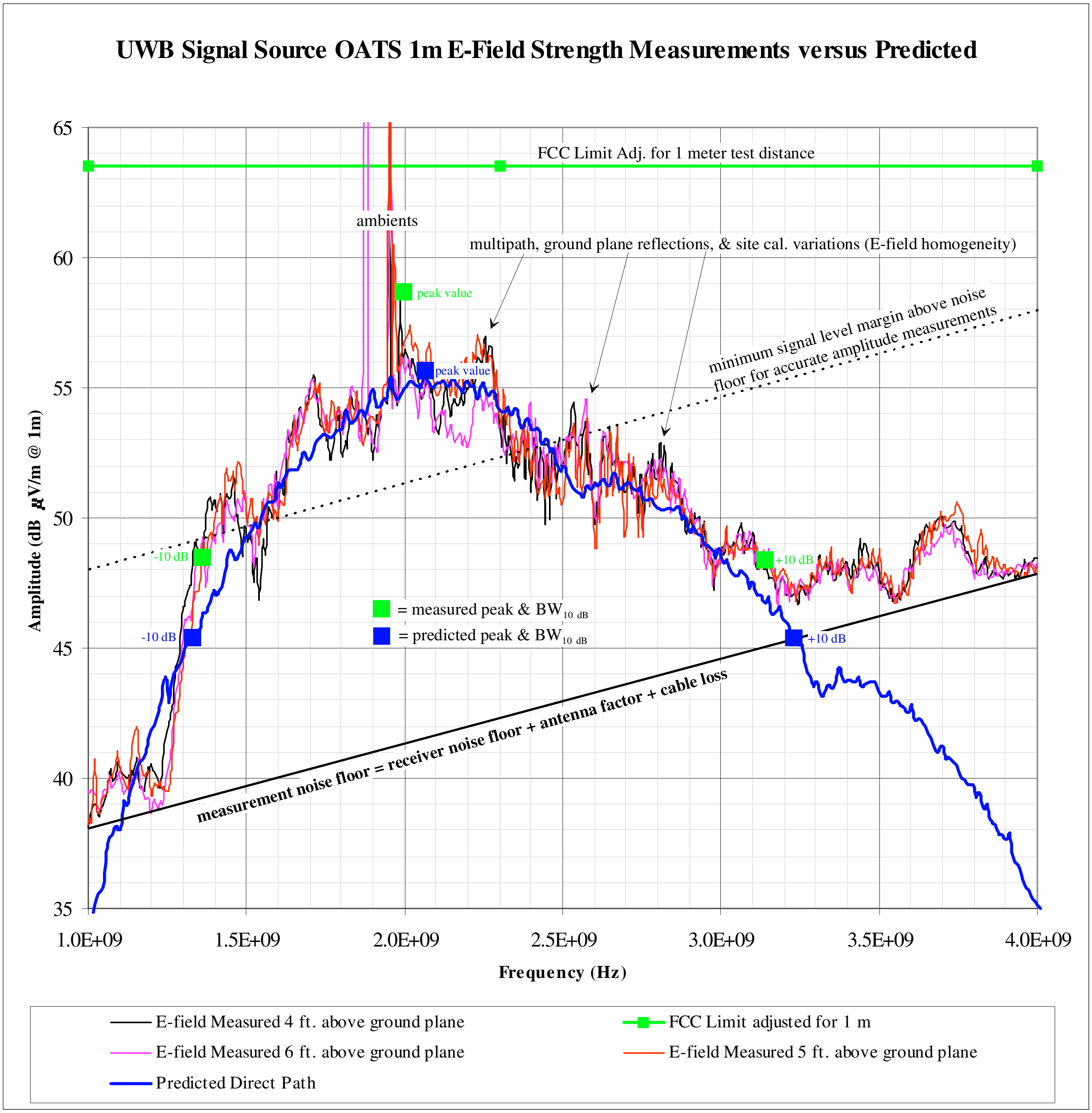


**Figure 10**. UWB OATS E-Field Measurements at 1 m versus Predicted

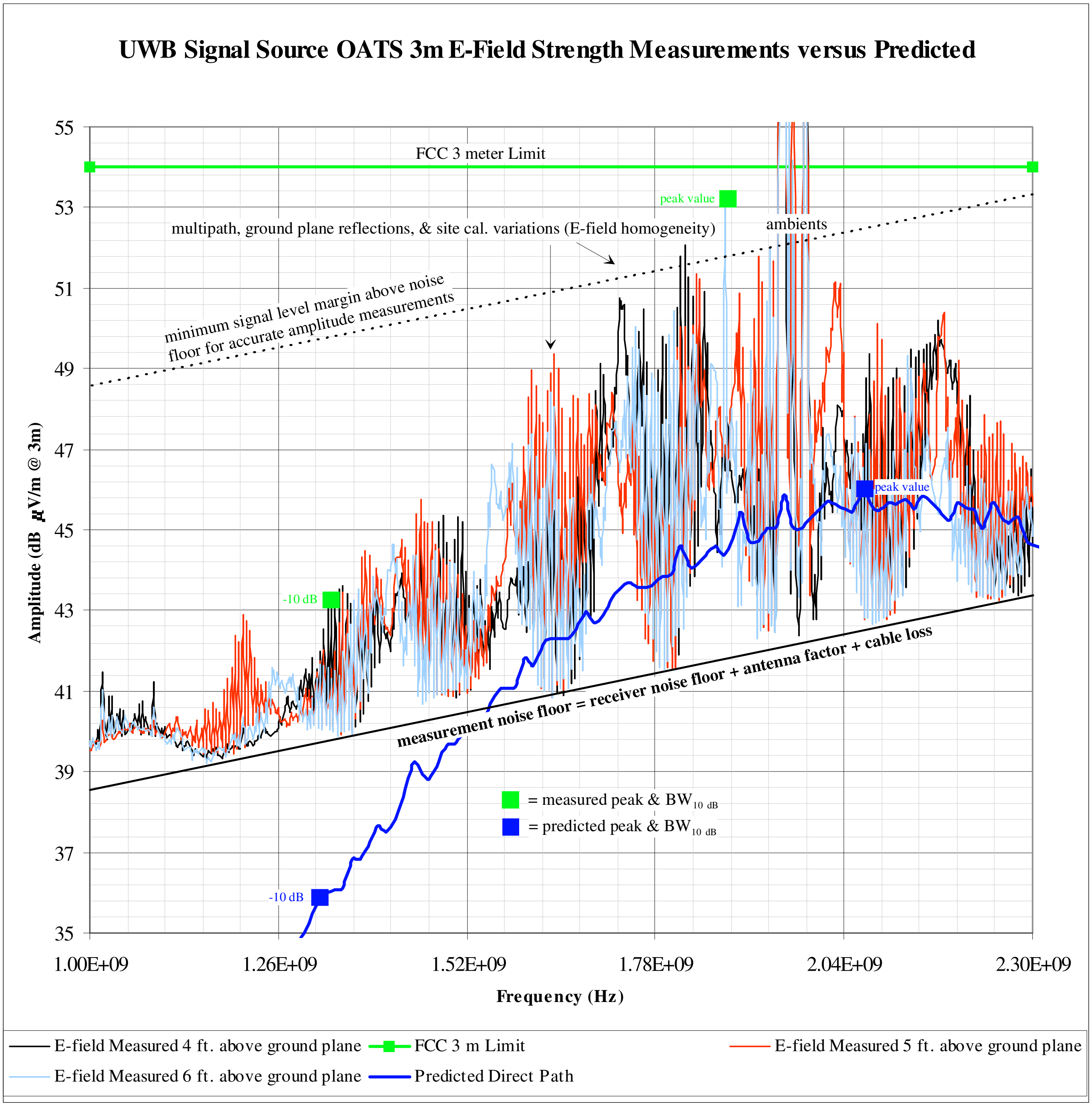


**Figure 11**. UWB OATS E-Field Measurements at 3 m versus Predicted

**Receiver Measurement Sensitivity**

Typical spectrum analyzer noise figures are on the order of 30 dB. According to page 79 of Engleson's book, *Modern Spectrum Analyzer Measurements*, in order to measure the amplitude of a noise like signal with an error less than 0.46 dB, the signal should be at least 10 dB above the receiving system noise floor. The noise floor of a receiver with a noise figure of 30 dB and a RBW of 1 MHz is approximately –84 dBm/MHz. According to E.I.R.P. calculations, the maximum transmit power that can be radiated in order to meet the 500 µV/m, at 3 meter, limit is –41.25 dBm/MHz. The path loss of 3 meters can be computed from Friis equation and is approximately 48 dB at 2 GHz. Subtracting the path loss from the maximum allowable transmit power yields a power at the receive antenna of –89.25 dBm/MHz.

The power at the receive antenna is 5 dB lower than the noise floor of the receiver. In order to meet the 10 dB margin, assuming no cable loss or noise contribution due to the antenna, the antenna gain would have to be 15 dBi. A typical double-ridged guide horn antenna has a 3-meter gain of approximately 7 dBi at 2 GHz, which is 8 dB lower than necessary. In order to lower the noise floor of the measurement system an external preamp can be used in front of the receiver. The typical noise figure of a broadband preamp, like the HP8449B, is 7 to 11 dB with a gain of approximately 30 dB. The receiving system noise figure would decrease to approximately 7.78 dB, using a 7 dB noise figure for the preamp, yielding a noise floor of –106.22 dBm/MHz. With the horn gain of 7 dBi one could accurately measure, with a 10 dB margin, a signal at -103.22 dBm/MHz. In order to accurately measure the 10 dB bandwidth points of a UWB signal, assuming the peak is at the FCC three meter limit, one needs a receiving system noise floor of –109.25 dBm/MHz which is about 3 dB lower than the receiving system noise floor with the preamp. Even in this best case scenario, with no additional ambient, no additional antenna noise, no cable loss and with the preamp <u>one cannot accurately measure the 10 dB bandwidth points of the UWB signal at 3 meters, see figure 11</u>. <u>The same receiving system at 1 meter can accurately measure the 10 dB bandwidth points, see Figure 10</u>. At a distance of 1 meter, the power at the receive antenna would be approximately –79.71 dBm/MHz which would have 10 dB bandwidth points at a power level of –89.71 dBm/MHz. Measuring this would require a noise floor of -99.71

dBm/MHz which is 9.54 dB higher than -109.25 dBm/MHz. In sum, accurate measurements will necessitate using 1 meter as the measurement distance if the emissions are to be sufficiently distinguished from noise.

**Measurement Site**

TDC believes that the optimal way to perform radiated emission measurements of UWB signals is in an anechoic chamber at a test distance of 1 meter. The chamber could be either semi or fully anechoic and have a quiet zone in the frequency range of 1 to 10 GHz. Most anechoic chambers are sufficient to measure narrowband signals because they have been characterized and mapped to determine transverse electric modes (TEM) and resonant peaks and null locations. A UWB signal can simultaneously excite all modes and resonances of a chamber within a 1 to 10 GHz bandwidth which will emphasize and de-emphasize portions of the UWB spectrum. TDC has performed measurements at 1 meter in a semi anechoic chamber and compared the measurements to those measured at an OATS and as predicted the chamber emphasized portions of the UWB spectrum. A chamber that has a 2 meter high by 2 meter wide quiet zone with approximately 20 dB of reflection loss between 1 and 10 GHz will yield a very accurate measurement of an UWB spectrum.

**Average and Quasi-peak Measurements**

When measured with a resolution bandwidth that is less than the pulse repetition frequency (PRF), a time-modulated UWB signal has characteristics much like Gaussian noise and measurement of the average value of the UWB signal is basically the same as measuring noise power, similar to what is explained in HP application note 150-4.[39] The UWB average power increases and decreases according to the relationship $10\text{Log}_{10}$(RBW ratio) as long as the RBW is lower than the PRF. TDC believes that the measurement

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[39] *See* HP App. Note 150-4, "Spectrum Analysis….Noise Measurements", Apr. 1974. Not all UWB emissions appear to be like Gaussian noise. If the receiving bandwidth is greater than the PRF or if the UWB PRF is not time hopped, then the emissions will not appear to be noise like.

receiver should use a RBW of 1 MHz; VBW should be at least 100 times smaller than the RBW, for effective averaging, but greater than 10 Hz. This is the same approach as the one currently employed by Part 15, and TDC agrees with the Commission's proposal to use it. It should be noted the UWB technology is an evolving technology. TDC is pleased that, as the technology evolves, the Commission will continue to monitor the applicability of its measurement procedures to the new technology and revise those procedures as needed.

Quasi-peak measurements will only be necessary for frequencies below 1 GHz. The only systems that are likely to have their center frequencies of operation in this part of the spectrum will be GPRs. TDC suggests that the Commission measure the "leakage" energy from the GPRs and not the primary energy radiated since most of this will be directed into the ground.

**Peak Measurements**

The peak measurements proposed in the NPRM are to be performed in the time domain rather than the traditional frequency domain. This provides a challenge in that the limits are related to frequency domain values. The two sections below highlight our questions and comments on the two different peak methods.

Some general comments on time domain measurements are applicable to both methods. First, TDC has experimental evidence that a standard gain horn antenna, such as the EMCO 3115, has low enough phase dispersion to allow an accurate time and frequency domain measurement of the UWB signal provided the time domain characteristics of other components in the measurement system are compensated for. Generally, laboratories providing certification data to the Commission do not have the requisite equipment or expertise to perform time domain measurements. If the Commission adopts specifications requiring time domain measurements, *i.e.,* peak level measurements, TDC suggests that the Commission allow the UWB manufacturers to perform the time domain measurements and present it to the Commission as part of the certification process, since UWB manufacturers can be expected to have such equipment for design and development. Moreover, TDC highlights that the sections discussed earlier about measurement distances of 1 meter and the usage of anechoic chambers are even more important for time domain measurements since the pulse will need to internally trigger a fast digital sampling oscilloscope (DSO), which tends to have poor sensitivity for such measurements. Overall, TDC suggests that the Commission not use time domain measurement techniques for UWB signals due to the complexity and lack of equipment available at test labs. Further, there is no analysis that indicates such a measurement provides useful information regarding the interference potential of UWB or other transmitters.

**Total Peak Measurements**

TDC found that it is very difficult to perform the total peak measurements and relate the time domain measured value to an absolute frequency domain value. This is a mathematically intensive task since the antenna gain, cable losses, LNA gain are all provided in terms of gain/loss versus frequency, but the waveform is a time domain plot. Instead, the easiest way to perform the total peak measurement is on a relative basis. With the time domain measurement setup, the pulse width and time between consecutive pulses can be measured and a duty cycle calculated from that. For instance, a pulse width of 1 nanosecond, and pulse interval of 1 microsecond yields a peak to average ratio of 20log(1 microsecond/1 nanosecond) = 60 dB. The time domain plot can be used to verify the pulse width and interval between pulses, without having to calibrate the setup to an absolute electric field strength value at some frequency. Conversely, the same calculation can be performed in the frequency domain. The peak to average duty cycle can be calculated as the 10 dB bandwidth divided by the spacing of the comb lines (for a system without any dithering or time-modulation). The 10 dB bandwidth is equivalent to the inverse of the pulse width, and the spacing of the comb lines is equivalent to the PRF that is the inverse of the interval between pulses. Nevertheless, TDC still does not see the value in measuring or calculating the "total peak" of a UWB emitter since no other receiver will ever intercept that much energy (except another UWB receiver and they have worse things with which to contend). Accordingly, if the procedures are to require measurements of “total peak power,” TDC urges the Commission to clarify this issue by detailing the procedure and equipment it envisions as being appropriate to make the measurement as well as its analysis that generated the concern for measuring this parameter.

**Frequency Range of Measurement**

TDC agrees with the proposal of the FCC to determine the bandwidth of a UWB emitter by using the –10 dB points, as well as determining the center frequency as the midpoint between the –10 dB points. This measurement needs to be done at a distance of 1 meter from the UWB device to the measuring antenna, because at 3 meters the sensitivity (even with a low noise amplifier) is so poor that it is difficult to measure the 10 dB points. The ealier discussion about receiver sensitivity clearly shows that it would be nearly impossible to obtain an accurate reading of the 20 dB bandwidth, and at a distance of 3 meters it is nearly impossible to measure the 10 dB bandwidth.

***Prohibition Against Damped Wave Emissions***

TDC agrees with the FCC's conclusion on the issue of the prohibition against class B, damped wave emissions as it does not appear to be relevant to the current proposed UWB technologies.

***Other Matters***

The Commission invited comments at Paragraph 58 of the NPRM as to whether Section 15.215(c) of the existing rules should be amended to clarify that Sections 15.215 – 15.255 do not apply to UWB operations. The agency proposed to stipulate that devices that would operate under Sections 15.215 to Section 15.255 "must be designed to ensure that the main lobe or the necessary bandwidth, whichever is less, is contained within the frequency bands designated in those rule sections under which the equipment is operated." If the Commission adopts such a change in the rules, it should make clear that the regulations do not preclude dual mode devices, provided that each mode of operation qualifies separately under the regulations that pertain to it. Thus, as discussed in the public interest section of these comments, there could be situations where consumers could be well served if RF devices featured multiple modes. This might, for example, involve a UWB device for ranging and tracking coupled with a spread spectrum or U-NII device for communications. Other devices might use UWB and spread spectrum capabilities simultaneously or alternatively, depending on the operating environment and the communications needs.

The discussion in Paragraph 58 of the NPRM also implies that emissions outside of "the main lobe" would be treated as *spurious* emissions and, thus, subject only to meeting the general limits of Section 15.209 of the Rules even if these emissions were to fall within the restricted bands set forth in Section 15.205 of the Rules. The question of what should constitute a *spurious* emission within the Part 15 context has proved vexing and will continue to do so. To the extent that energy from modulation products associated with Part 15 devices that generate wideband emissions fall within a restricted band, the Commission has adopted an informal policy, which Time Domain deems reasonable and appropriate, that treats these emissions as spurious emissions even though they are technically defined as out-of-band emissions.[40] Thus, out-of-band emissions are permitted to radiate at a 500 µV/m level measured at 3 meters.

If the Commission had not adopted this policy, the result would have been the waste of valuable spectrum because wideband devices would have to move their channel of operation well away from the band edge. Consider, for example, the following case: U-NII devices are permitted to operate in the 5.25 to 5.35 GHz band and are encouraged by the Part 15 rules to utilize wideband modulation formats of around 20 MHz. The band from 5.35 to 5.46 GHz is a restricted band. Thus, an overly literal interpretation of the Part 15 rules would not permit out-of-band emissions from a UNII device in the restricted band from 5.35 to 5.46 GHz. So, in order for a UNII device operating in the 5.25 to 5.35

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[40] Section 2.1 of the Rules defines the term *spurious emission* as an "[e]mission on a frequency or frequencies which are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products, but exclude out-of-band emissions." The term *out-of-band emissions* is defined in Section 2.1 as an "[e]mission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emissions."

GHz band using a 20 MHz emission bandwidth to meet a strict interpretation of the Part 15 rules, it would have to keep its channel of operation approximately 30 MHz from the band edge at 5.35 GHz resulting in the waste of approximately 30% of the spectrum in the allocation.

Nevertheless, at the signal levels involved, the important point is that regardless of the characterization of the energy, such emissions are perceived by other receivers as noise. If the signal of a UWB device were to place energy into a restricted band at the same or lower level as an intentional radiator operating under Sections 15.217 – 15.255 of the Rules, logically the emission from the UWB device should be permitted even though it, too, may not literally fall within the definition of *spurious.*

## **Conclusion**

This rule making affords an opportunity for the Commission once more to meet its statutory obligation to advance the public interest by adopting regulations that will foster the development of beneficial new technologies that can save lives and enable more efficient use of spectrum. In making such changes, the Commission would be building upon the successful spectrum sharing that has been the hallmark of Part 15 of the agency's rules.

To be sure, UWB poses challenges, but the path is hardly uncharted. For more than two decades, the Commission has gained valuable insight through application of the Part 15 general limits, particularly those regulating emissions from unintentional radiators such as digital devices. By adopting regulations that will permit UWB devices to emit signals that are similar to, and at the same field strength levels as the noise now allowed to be radiated by digital devices, the Commission will make it possible for a host of publicly useful applications to be implemented at signal levels that heretofore were thought largely too low for many useful communications radar and tracking/location applications.

The risks associated with the implementation of regulations that will permit UWB technology to be employed in this manner, pale in comparison to the risks of not moving forward. A lack of progress risks not only national technological leadership, but would, more importantly, deprive the public of a valuable new tool for making better use of radio. TDC urges the Commission to move expeditiously in this proceeding and looks forward to continued participation.

Respectfully,

Time Domain Corporation

By: *submitted electronically*
Paul Withington
Vice President

7057 Old Madison Pike
Huntsville, AL 35806

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